Global Positioning System

Overview

- Official name of GPS is NAVigational Satellite Timing And Ranging Global Positioning System (NAVSTAR GPS)
- Global Positioning Systems (GPS) is a form of Global Navigation Satellite System (GNSS)
  - Only completely functional one of its kind at this time
- First developed by the United States Department of Defense
- Consists of two dozen GPS satellites in medium Earth orbit (The region of space between 2000km and 35,786 km)

Overview (continued)

- Made up of two dozen satellites working in unison are known as a satellite constellation
- This constellation is currently controlled by the United States Air Force 50th Space Wing
- It costs about $750 million to manage and maintain the system per year
- Mainly used for navigation, map-making and surveying

Operation Overview

- A GPS receiver can tell its own position by using the position data of itself, and compares that data with 3 or more GPS satellites.
- To get the distance to each satellite, the GPS transmits a signal to each satellite.
    - The signal travels at a known speed.
    - The system measures the time delay between the signal transmission and signal reception of the GPS signal.
    - The signals carry information about the satellite's location.
    - Determines the position of, and distance to, at least three satellites, to reduce error.
    - The receiver computes position using trilateration.

GPS Functionality

- GPS systems are made up of 3 segments
  - Space Segment (SS)
  - Control Segment (CS)
  - User Segment (US)

Space Segment

- GPS satellites fly in circular orbits at an altitude of 20,200 km and with a period of 12 hours.
- Powered by solar cells, the satellites continuously orient themselves to point their solar panels toward the sun and their antenna toward the earth.
- Orbital planes are centered on the Earth
- Each planes has about 55° tilt relative to Earth's equator in order to cover the polar regions.

Space Segment (Continued)

- Each satellite makes two complete orbits each sidereal day.
  - Sidereal - Time it takes for the Earth to turn 360 degrees in its rotation
- It passes over the same location on Earth once each day.
- Orbits are designed so that at the very least, six satellites are always within line of sight from any location on the planet.

Space Segment (Continued)

- There are currently 30 actively broadcasting satellites in the GPS constellation.
- Redundancy is used by the additional satellites to improve the precision of GPS receiver calculations.
- A non-uniform arrangement improves the reliability and availability of the system over that of a uniform system, when multiple satellites fail
- This is possible due to the number of satellites in the air today

Control Segment

- The CS consists of 3 entities:
  - Master Control System
  - Monitor Stations
  - Ground Antennas

Master Control Station

- The master control station, located at Falcon Air Force Base in Colorado Springs, Colorado, is responsible for overall management of the remote monitoring and transmission sites.
- GPS ephemeris is the tabulation of computed positions, velocities and derived right ascension and declination of GPS satellites at specific times for eventual upload to GPS satellites.

Monitor Stations

- Six monitor stations are located at Falcon Air Force Base in Colorado, Cape Canaveral, Florida, Hawaii, Ascension Island in the Atlantic Ocean, Diego Garcia Atoll in the Indian Ocean, and Kwajalein Island in the South Pacific Ocean.
- Each of the monitor stations checks the exact altitude, position, speed, and overall health of the orbiting satellites.

Monitor Stations (continued)

- The control segment uses measurements collected by the monitor stations to predict the behavior of each satellite's orbit and clock.
- The prediction data is up-linked, or transmitted, to the satellites for transmission back to the users.
- The control segment also ensures that the GPS satellite orbits and clocks remain within acceptable limits. A station can track up to 11 satellites at a time.

Monitor Stations (continued)

- This "check-up" is performed twice a day, by each station, as the satellites complete their journeys around the earth.
- Variations such as those caused by the gravity of the moon, sun and the pressure of solar radiation, are passed along to the master control station.

Ground Antennas

- Ground antennas monitor and track the satellites from horizon to horizon.
- They also transmit correction information to individual satellites.

User Segment

- The user's GPS receiver is the US of the GPS system.
- GPS receivers are generally composed of an antenna, tuned to the frequencies transmitted by the satellites, receiver-processors, and a highly-stable clock, commonly a crystal oscillator).
- They can also include a display for showing location and speed information to the user.
- A receiver is often described by its number of channels this signifies how many satellites it can monitor simultaneously. As of recent, receivers usually have between twelve and twenty channels.

User Segment (continued)

- Using the RTCM SC-104 format, GPS receivers may include an input for differential corrections.
  - This is typically in the form of a RS-232 port at 4,800 bps speed. Data is actually sent at a much lower rate, which limits the accuracy of the signal sent using RTCM.
- Receivers with internal DGPS receivers are able to outclass those using external RTCM data.

Navigational Systems

- GPS satellites broadcast three different types of data in the primary navigation signal.
  - Almanac – sends time and status information about the satellites.
  - Ephemeris – has orbital information that allows the receiver to calculate the position of the satellite.
    - This data is included in the 37,500 bit Navigation Message, which takes 12.5 minutes to send at 50 bps.

Navigational Systems (cont'd)

- Satellites broadcast two forms of clock information
  - Coarse / Acquisition code (C/A) - freely available to the public. The C/A code is a 1,023 bit long pseudo-random code broadcast at 1.023 MHz, repeating every millisecond.
  - Restricted Precise code (P-code) - reserved for military usage. The P-code is a similar code broadcast at 10.23 MHz, but it repeats only once a week. In normal operation, the anti-spoofing mode, the P code is first encrypted into the Y-code, or P(Y), which can only be decrypted by users a valid key.

GPS Frequencies

- L1 (1575.42 MHz) - Mix of Navigation Message, coarse-acquisition (C/A) code and encrypted precision P(Y) code.
- L2 (1227.60 MHz) - P(Y) code, plus the new L2C code on the Block IIR-M and newer satellites.
- L3 (1381.05 MHz) - Used by the Defense Support Program to signal detection of missile launches, nuclear detonations, and other applications.

GPS Proposed Frequencies

- L4 (1379.913 MHz) - Being studied for additional correction to the part of the atmosphere that is ionized by solar radiation.
- L5 (1176.45 MHz) – To be used as a civilian safety-of-life (SoL) signal.
  - Internationally protected range for aeronautical navigation.
  - The first satellite that using this signal to be launched in 2008.

Position Calculation

- The coordinates are calculated according to the World Geodetic System WGS84 coordinate system.
- The satellites are equipped with atomic clocks
- Receiver uses an internal crystal oscillator-based clock that is continually updated using the signals from the satellites.
- Receiver identifies each satellite's signal by its distinct C/A code pattern, then measures the time delay for each satellite.

Position Calculation (cont'd)

- The receiver emits an identical C/A sequence using the same seed number the satellite used.
- By aligning the two sequences, the receiver can measure the delay and calculate the distance to the satellite, called the pseudorange.
- Orbital position data from the Navigation Message is used to calculate the satellite's precise position. Knowing the position and the distance of a satellite indicates that the receiver is located somewhere on the surface of an imaginary sphere centered on that satellite and whose radius is the distance to it.

Position Calculation (cont'd)

- When four satellites are measured at the same time, the point where the four imaginary spheres meet is recorded as the location of the receiver.
- Earth-based users can substitute the sphere of the planet for one satellite by using their altitude. Often, these spheres will overlap slightly instead of meeting at one point, so the receiver will yield a mathematically most-probable position.

Issues That Affect Accuracy

- Changing atmospheric conditions change the speed of the GPS signals as they pass through the Earth's atmosphere and ionosphere.
  - Effect is minimized when the satellite is directly overhead
  - Becomes greater for satellites nearer the horizon, since the signal is affected for a longer time.
  - Once the receiver's approximate location is known, a mathematical model can be used to estimate and compensate for these errors.

Issues That Affect Accuracy (cont’d)

- Clock Errors can occur when, for example, a GPS satellite is boosted back into a proper orbit.
  - The receiver's calculation of the satellite's position will be incorrect until it receives another ephemeris update.
  - Onboard clocks are accurate, but they suffer from partial clock drift.

Issues That Affect Accuracy (cont'd)

- GPS Jamming can be used to limit the effectiveness of the GPS signal
  - For example, it is believed GPS guided missles have been misled to attack non-target locations in the war in Afghanistan.
  - The stronger the jamming signal, the more interference can be caused to the GPS signal.

Issues That Affect Accuracy (cont'd)

- GPS signals can also be affected by multipath issues
  - Radio signals reflect off surrounding objects at a location. These delayed signals can cause inaccuracy.
  - Less severe in moving vehicles. When the GPS antenna is moving, the false solutions using reflected signals quickly fail to converge and only the direct signals result in stable solutions.

Methods of Improving Accuracy

- Precision monitoring
  - Dual Frequency Monitoring
    - Refers to systems that can compare two or more signals
    - These two frequencies are affected in two different ways. How they are affected can be predicted however
    - After monitoring these signals, it's possible to calculate what the error is and eliminate it
    - Receivers that have the correct decryption key can decode the P(Y)-code transmitted on signals to measure the error.

Methods of Improving Accuracy (cont'd)

- Carrier-Phase Enhancement (CPGPS)
  - CPGPS uses the L1 carrier wave, which has a period 1000 times smaller than that of the C/A bit period, to act as an additional clock signal and resolve uncertainty.
  - The phase difference error in the normal GPS amounts to between 2 and 3 meters (6 to 10 ft) of ambiguity.
  - CPGPS works to within 1% of perfect transition to reduce the error to 3 centimeters (1 inch) of ambiguity.
  - By eliminating this source of error, CPGPS coupled with DGPS normally realizes between 20 and 30 centimeters (8 to 12 inches) of absolute accuracy.

Methods of Improving Accuracy (cont'd)

- Relative Kinematic Positioning (RKP)
  - Determination of range signal can be resolved to an accuracy of less than 10 centimeters (4 in).
  - Resolves the number of cycles in which the signal is transmitted and received by the receiver.
  - Accomplished by using a combination of DGPS correction data, transmitting GPS signal phase information and ambiguity resolution techniques via statistical tests — possibly with processing in real-time.

Methods of Improving Accuracy (cont'd)

- Augmentation
  - Relies on external information being integrated into the calculation process.
  - Some augmentation systems transmit additional information about sources of error.
  - Some provide direct measurements of how much the signal was off in the past
  - Another group could provide additional navigational or vehicle information to be integrated in the calculation process.

Applications – Military

- Military GPS user equipment has been integrated into fighters, bombers, tankers, helicopters, ships, submarines, tanks, jeeps, and soldiers' equipment.
- In addition to basic navigation activities, military applications of GPS include target designation of cruise missiles and precision-guided weapons and close air support.
- To prevent GPS interception by the enemy, the government controls GPS receiver exports
- GPS satellites also can contain nuclear detonation detectors.

Applications – Civilian

- Automobiles are often equipped GPS receivers.
  - They show moving maps and information about your position on the map, speed you are traveling, buildings, highways, exits etc.
  - Some of the market leaders in this technology are Garmin and TomTom, not to mention the built in GPS navigational systems from automotive manufacturers.

Applications – Civilian (cont’d)

- For aircraft, GPS provides
  - Continuous, reliable, and accurate positioning information for all phases of flight on a global basis, freely available to all.
  - Safe, flexible, and fuel-efficient routes for airspace service providers and airspace users.
  - Potential decommissioning and reduction of expensive ground based navigation facilities, systems, and services.
  - Increased safety for surface movement operations made possible by situational awareness.

Applications – Civilian (cont’d)

- Agriculture
  - GPS provides precision soil sampling, data collection, and data analysis, enable localized variation of chemical applications and planting density to suit specific areas of the field.
  - Ability to work through low visibility field conditions such as rain, dust, fog and darkness increases productivity.
  - Accurately monitored yield data enables future site-specific field preparation.

Applications – Civilian (cont'd)

- Disaster Relief
  - Deliver disaster relief to impacted areas faster, saving lives.
  - Provide position information for mapping of disaster regions where little or no mapping information is available.
  - Example, using the precise position information provided by GPS, scientists can study how strain builds up slowly over time in an attempt to characterize and possibly anticipate earthquakes in the future.

Applications – Civilian (cont'd)

- Marine applications
  - GPS allows access to fast and accurate position, course, and speed information, saving navigators time and fuel through more efficient traffic routing.
  - Provides precise navigation information to boaters.
  - Enhances efficiency and economy for container management in port facilities.

Applications – Civilian (cont'd)

- Other Applications not mentioned here include
  - Railroad systems
  - Recreational activities (returning to the same fishing spot)
  - Heading information – replacing compasses now that the poles are shifting
  - Weather Prediction
  - Skydiving – taking into account winds, plane and dropzone location
  - Many more!